blindly enraptured with that theory, as he is pleased to state, I only reply that very clever men have held it, as he is perhaps aware; and certainly none of the modern theories, cumbrous vagaries of the brain, can compare with it. I have never said that the meteoric theory is the real explanation, but I doubt if we shall ever arrive at a more truthful representation of the solar phenomena.

Lastly, he culminates by saying I am "either innocently or wilfully ignorant of the palpably cyclonic appearance which spots frequently present." All I can say in answer to this is that, having observed sun-spots myself for many years, probably as often as the reviewer, I have *never* observed one single appearance of a cyclonic nature. As I possess Mr. Carrington's valuable work, I have again referred to it, and find it in agreement with the assertion in my book and my own observation. I must apologise for my lengthy letter. A. M. DAVIES

2, Gloucester Terrace, Sandgate, July 4

On an Error in Regnault's Calculation of the Heat Converted into Work in the Steam Engine

IN Watts's "Dictionary of Chemistry" (vol. iii. p. 125), in the article on Heat by Prof. G. C. Foster, it appears to me that an important error has crept into the discussion of the above calculation.

The nature of the calculation is as follows:—A unit weight of saturated steam at the temperature of 152°C. contains 653 units of heat. Suppose we allow the steam to expand and to do work until the temperature falls to 503°C. the steam then contains 621 units or 32 units less than before, hence starting with water at 0°C., we give it 653 units of heat, and of this 32 only are converted into work, giving us the fraction $\frac{32}{653}$ as the amount of heat converted into work; but the real work produced by an engine is more than twice this. This difference in theory and practice is accounted for by the fact that saturated steam, in expanding and doing work, is partly condensed, hence the body with which we have to deal at the lower temperature is not all steam, but partly condensed water, therefore, does not contain so much heat as was allowed it.

This explanation is so intelligible as to be at first sight sufficient to account for the whole difference; there is, however, another cause, quite as important, and which is this; every time steam passes from the boiler to the cylinder it does work before it is cut off, and allowed to expand; this work is not done at the expense of the steam that passes into the cylinder, but of the whole mass of steam in the cylinder and boiler, which expands and is thereby cooled. The mass of water and steam in the boiler is, however, so large compared to that which passes into the cylinder, that a thermometer could scarcely detect the cooling effect upon it, and before the next stroke this loss of temperature is made up by the fire. Though thus inappreciable, it is nevertheless very important, and in most engines would amount to one-third the work done; in fact all the work done by the steam before it is cut off and allowed to expand is entirely neglected in this calculation, and a source of error introduced.

To correct it there should be added to the heat in the steam at the initial temperature, as many units of heat as the work done before the steam is cut off, would, if converted into heat, raise the amount of water which passes at every stroke in the form of steam into the cylinder. A. W. BICKERTON

Hartley Institution, Southampton, June 26

THE CAUSES OF THE COLOURS OF THE SEA *

PROF. TYNDALL, in his article in the *Fortnightly Review* for the 1st of March, attributes the greenness of the sea to the matter which it holds in solution. Perhaps the following may corroborate his theory. About the Andaman Islands, where the sea is of the deepest blue, there are most startling and sharply-defined changes of colour, from bright blue to green, where a bed of coral exists. This coral is white out of the water, what its colour when growing may be I know not, but the change I mention appears to corroborate the remarks in the article in question, which are appended below, about the green hues observed upon the plate, the screw blades, and the white bellies of the porpoises. One looks down from a hill into a bay of the brightest blue; you see it broken up here and there like a child's puzzle map by irregular patches of as bright green, often crossing several acres as sharply defined as it is possible to imagine, and indicating the existence of coral beds or reefs just below.

Bellary, Madras Presidency W. M'MASTER

[We give the passages referred to from Prof. Tyndall's lecture.—ED.]

"Let us clear our way by a few experiments towards an explanation of the dark hue of the deep ocean.* Colour, you know, resides in white light, appearing generally when any constituent of the white light is withdrawn. Here is a liquid which colours a beam sent through it purple, and this colour is immediately accounted for by the action of the solution on a spectrum. It cuts out the yellow and green, and allows red and blue to pass through. The blending of these two colours produces the purple. Does the liquid allow absolutely free passage to the red and blue? No. It enfeebles the whole spectrum, but attacks with special energy the yellow and green colours. By increasing the thickness of the stratum traversed by the beam, we cut off the whole of the spectrum. Through the deeper layer, which I now place in the path of the beam, no colour can pass. Here, again, is a blue liquid. Why is it blue? Its action on the spectrum answers the question. It first extinguishes the red; then as the thickness augments it attacks the orange, yellow, and green in succession; the blue alone finally remains, but everything might be extinguished by a sufficient depth of the liquid.

"And now we are prepared for a concentrated but tolerably complete statement of the action of sea water upon light, to which it owes its blackness. Here is our spectrum. This embraces three classes of rays—the thermal, the visual, and the chemical. These divisions overlap each other; the thermal rays are in part visual, the visual rays in part chemical, and *vice versâ*. The vast body of thermal rays is here beyond the red and invisible. They are attacked with exceeding energy by water. They are absorbed close to the surface of the sea, and are the great agents in evaporation. At the same time the whole spectrum suffers enfeeblement; water attacks all its rays, but with different degrees of energy. Of the visual rays the red are attacked first, and first extinguished. While the red is extinguished, the remaining colours are enfeebled. As the solar beam plunges deeper into the sea, orange follows red, yellow follows orange, green follows yellow, and the various shades of blue, where the water is deep enough, follow green. Absolute extinction of the solar beam would be the consequence if the water were deep and uniform, and contained no suspended matter. Such water would be as black as ink. A reflected glimmer of ordinary light would reach us from its surface, as it would from the surface of actual ink; but no light, hence no colour, would reach us from the body of the water. In very clear and very deep sea water this condition is approximately fulfilled, and hence the extraordinary darkness of such water. The indigo, to which I have already referred, is, I believe, to be ascribed in part to the suspended matter, which is never absent, even in the purest natural water, and in part to the slight reflection of the light from the limiting surfaces of strata of different densities. A modicum of light is thus thrown back to the eye, before the depth necessary to absolute extinction has been attained. An effect precisely similar occurs under the moraines of the Swiss glaciers. The ice here is exceptionally compact, and owing to the absence of the internal scattering common in bubbled ice, the light plunges into the mass, is extinguished, and the perfectly clear ice presents an appearance of pitchy blackness.

"The green colour of the sea when it contains matter in a state of mechanical suspension has now to be accounted for; and here, again, let us fall back upon the sure basis of experiment. This white plate was once a complete dinner-plate, very thick and strong. It is, you see, surrounded securely by cord, and to it a lead weight is fastened. Forty or fifty yards of strong hempen line were attached to the plate. With it in his hand, my assistant, Thorogood, occupied a boat fastened as usual to the davits of

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* Communicated by Prof. Tyndall.

* A note written to me the 22nd of October, by my friend Canon Kingsley, contains the following reference to this point:—"I have never seen the Lake of Geneva, but I thought of the brilliant, dazzling dark blue of the mid Atlantic under the sunlight, and its black blue under-cloud, both so solid that one might leap off the sponson on to it without fear; this was to me the most wonderful thing which I saw on my voyage to and from the West Indies."—J. T.

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the *Urgent*, while I occupied a second boat nearer to the stern of the ship. He cast the plate as a mariner heaves the lead, and by the time it had reached me, it had sunk a considerable depth in the water. In all cases the hue of this plate was green, not, of course, a pure green, but a mixture of green and blue; and when the sea was of the darkest indigo, the green was the most vivid and pronounced. I could notice the gradual deepening of the colour as the plate sank, but at its greatest depth in indigo water the colour was still a blue green.

"Other observations confirmed this one. The *Urgent* is a screw steamer, and right over the blades of the screw there was an orifice called the screw-well, through which you could look from the poop down upon the screw. The surface glimmer which so pesters the eye was here in a great measure removed. Midway down a plank crossed the screw-well from side to side, and on this I used to place myself to observe the action of the screw underneath. The eye was rendered sensitive by the moderation of the light; and still further to remove all disturbing causes, Lieutenant Walton had the great kindness to have a sail and tarpaulin thrown over the mouth of the well. Underneath this I perched myself, and watched the screw. In an indigo sea the play of colours was indescribably beautiful, and the contrast between the water which had the screw-blades for a background, and that which had the bottom of the ocean as a background, was extraordinary. The one was of the most brilliant green, the other of the most lustrous ultramarine. The surface of the water above the screw-blade was always ruffled. Liquid lenses were thus formed, by which the coloured light was withdrawn from some places and concentrated upon others. The screw-blades in this case replaced the plate in the former case, and there were other instances of a similar kind. The hue from an indigo sea was always green at a certain depth below the surface. The white bellies of the porpoises showed the same hue, varying in intensity as the creatures swung to and fro between the surface and the deeper water. In a rough sea the light which had penetrated the summit of a wave sometimes reached the eye. A beautiful green cap was thus placed upon the wave when the ship was in indigo water.

"But how is this colour to be connected with the suspended particles? Take the dinner-plate which showed so brilliant a green when thrown into indigo water. Suppose it to diminish in size until it reached an almost microscopic magnitude. It would still behave substantially as the larger plate, sending to the eye its modicum of green light. If the plate, instead of being a large coherent mass, were ground to a powder sufficiently fine, and in this condition diffused through the clear sea water, it would send green to the eye. In fact, the suspended particles which the home examination revealed in green sea water act in all essential particulars like the plate, or like the screw-blades, or like the foam, or like the bellies of the porpoises. When too gross, or in too great quantity, the suspended particles thicken the sea itself visibly. But when sufficiently small, but not too small, and when sufficiently diffused, they do not sensibly interfere with the limpid greenness of the sea itself. They then require the stronger and more delicate test of the concentrated luminous beam to reveal their presence."

THE TEMPERATURE OF THE SUN

PROF. NEWCOMB, in reviewing P. A. Secchi's work on the Sun, shows that if the temperature reached 10,000,000° Cent., as asserted by the author of "Le Soleil," the earth would speedily be reduced to vapour. In answer to this objection Pére Secchi urges, "that a body may have a very high temperature and yet radiate but very little;" contending that "a thermometer dipped inside the solar envelope in contact with the photosphere," would indicate the temperature mentioned. He adds, "This high temperature, besides, is really a virtual temperature, as it is the amount of radiation received from all the transparent strata of the solar envelope, and this body at the outer shell must certainly be at a lower temperature." What information is intended to be conveyed by the statement that 10,000,000° Cent. "is really a virtual temperature," on the ground that it is the "amount of radiation received from all the transparent strata" outside of the photosphere, I will not attempt to explain; but I propose to show that a thermometer dipped inside the solar envelope in contact with the photosphere, cannot possibly indicate the enormous temperature of 10,000,000° Cent. assumed by Pére Secchi. The assertion that "a body may have a very high temperature and yet radiate but very little," were it correct with reference to the photosphere, does not affect the question. It is of no consequence whether the sun's photosphere belongs to the class of active or sluggish incandescent radiators imagined by the distinguished savan; the temperature of the radiant surface, not its capacity to radiate more or less copiously, is the problem to be solved. Accordingly the following statement is intended to show that the temperature of the sun's photosphere at the point where the author of "Le Soleil" supposes his thermometer to be applied, cannot much exceed 4,000,000° Fahr. Observations conducted in lat. 40° 42′, with an actinometer (a drawing of which has been published in *Engineering*) have enabled me to ascertain, with desirable accuracy, the intensity of solar radiation for each degree of the sun's zenith distance from 17° to 75°. The atmospheric depth at the first mentioned zenith distance being only 0·046 greater than the vertical atmospheric depth, I have demonstrated, by prolonging the curve constructed agreeable to the observations referred to, that the intensity of solar radiation on the ecliptic is 67·20° Fahr. at the time when the earth passes the aphelion. The accompanying table, the result of two years of observations, shows the atmospheric depth and the intensity of solar radiation for each degree from the vertical to 75° zenith distance. The ratio of diminution of intensity of the radiant heat during the passage of the rays through the atmosphere being accurately defined by this table, it has been easy to calculate that the amount of retardation of the radiant heat on the ecliptic is 0·207 or 17·64° Fahr. Adding this loss of energy to the amount of observed radiant heat, it will be found that the intensity of solar radiation at the boundary of our atmosphere when the earth passes the aphelion corresponds with a thermometric interval of $17{\cdot}64 + 67{\cdot}20 = 84{\cdot}84^\circ$ on the Fahrenheit scale. Now, the aphelion distance of the earth is 218·1 times greater than the radius of the sun's photosphere; hence, basing our calculations on the established truth that the intensities are inversely as the areas over which the rays are dispersed, we prove that the temperature of the photosphere is $218{\cdot}1^2 \times 84{\cdot}84^\circ = 4{,}035{,}584^\circ$ Fahr. And if we then add the amount of loss of intensity attending the passage of the rays through the solar envelope, we establish, with absolute certainty, the temperature to which a thermometer will be subjected if "dipped inside the solar envelope in contact with the photosphere."

With reference to the retardation of the rays in passing through the solar envelope, we possess practical data of such a nature that the solution of the problem is by no means mere hypothesis. We know that the density of atmospheric air would be reduced to $\frac{1}{8000}$ of the ordinary density if subjected to a temperature of 4,000,000° Fahr.; hence, if we assume that the solar envelope consists chiefly of hydrogen, it may be shown, due allowance being made for the superior attraction of the sun's mass, that the density of the terrestrial atmosphere at equal depth from the boundary is fully 2,000 times greater than that of the solar envelope. Accordingly, as the sun's rays lose only 17·6° in passing vertically through our cold atmosphere, it may be demonstrated that the loss of energy during the passage of the rays through a transparent solar envelope 80,000 miles in depth from the photosphere, cannot exceed 0·01 or 40,000° Fahr. Let us be careful not to confound this diminution of energy with the reduction of temperature consequent on the dispersion of the rays as they recede from the photosphere during their course through the solar envelope. The reduction of temperature attending dispersion, obviously does not involve any diminution of mechanical

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